Towards a more precise characterisation of creativity in AI

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Abstract

I summarise and attempt to clarify some concepts presented in and arising from Margaret Boden's (1990) descriptive hierarchy of creativity, by formalising the ideas she proposes. I exemplify their use by broadly describing the development of art music from the 10th to the 20th century in these more formal terms. I suggest that Boden's descriptive framework, once elaborated, is more powerful than it first appears.

Introduction

One of the few attempts to address the problem of creative behaviour in the early days of AI was that of Margaret Boden, perhaps best summarised in her book, *The Creative Mind* (Boden 1990). A common criticism of Boden's approach is that it is rather lacking in detail, and that it is not clear how the various components fit together to give a real account of creative behaviour.

Boden's ideas have been discussed at some length (Turner 1995; Schank & Foster 1995; Ram *et al.* 1995; Perkins 1995; Lustig 1995; Haase 1995), but little attempt has been made to give a mechanism through which they can be applied formally. In this paper, rather than entering into the debate above, which I leave for future work, I will attempt to make Boden's descriptive heirarchy more precise. In doing so, I will suggest some additions to the theory, which may or may not be implicit in Boden's account, and show how some of the distinctions over which she has been challenged may perhaps be supported. I will illustrate the points made by reference to an outline of the model's application to the development of Western art music during the 2nd Millennium AD.

I will conclude by suggesting that, once formalised, the power of Boden's proposal becomes rather more clear than before, and that it may not be idly dismissed as vague, as it sometimes has been in the past.

Boden's descriptive hierarchy

Boden (1990) aims to study the idea of AI-based simulation of creativity from a philosophical viewpoint. She begins by setting out two taxonomies of creative behaviour, in two orthogonal ways.

First, she makes the distinction between H- and P-creativity: creativity which is "historical" or "psychological", respectively. The distinction is between the sense of creating a concept which has never been created before at all, and a concept which has never been created before by a specific creator. This distinction will be only be tangentially relevant to my argument here.

Second, there is the distinction between *exploratory* and *transformational* creativity, which needs a little more explanation. Boden conceives of the process of creativity as the identification and/or location of new conceptual objects of a *conceptual space*. Subsequent authors have somtimes imagined the conceptual space to be the state space of Good Old Fashioned AI (though it is not clear that Boden intends her proposal to be taken so specifically or literally).

If we do make this assumption, then the creative act might be said to be exploring a search space of partial and complete possibilities, and this is the kind of creativity which Boden calls "exploratory". The existence of such a conceptual space begs a question (at least to the AI researcher!): what rules define the space? If there are rules which define the space, then, presumably, those rules can be changed, producing what might be thought of as a paradigm shift. This kind of change is "transformational" creativity to Boden.

However, it is not clear from Boden's writings about these ideas how she defines the particular set of rules which give rise to a particular conceptual space, and therefore what is the difference, in terms of the new concepts discovered, between exploring the space and transforming it. I will argue below that there is at least one way we can coherently make such a distinction. First, however, it is necessary to sharpen slightly the philosphical tools that Boden introduced.

A Universe of Possibilities

Boden's combination of the idea of the conceptual space with distinct notions of exploratory and transformational creativity has some consequences which are left implicit in her published work.

Most fundamentally, for transformational creativity to have any meaning, there must be a universe of possibilities, which I shall call $\mathcal{U}$, which is a *superset* of the conceptual space at any given point in the creative process. To see the reason for this, let us first define $\mathcal{U}$.

$\mathcal{U}$ is a multidimensional space, whose dimensions are capable of representing anything, and all possible distinct concepts correspond with distinct points in $\mathcal{U}$.

For parsimony, we could restrict $\mathcal{U}$ to be capable of representing just the things which are relevant to the domain in which we wish to be creative – but this would rule out cross-domain transfer of ideas, by processes such as analogy, which would be undesirable in general. (I return to analogy and other means of guiding exploratory creativity below.) To make my proposal as state-space-like as possible, let us assume that $\mathcal{U}$ contains all partial concepts as well as all complete ones, and that it is possible to distinguish between complete and incomplete. Henceforward I will refer to both partial and complete concepts simply as "concepts", except where the distinction is significant. It follows from the inclusion of partial concepts that we should also admit the most partial concept of all, the empty concept, which I will denote by $\perp$, and that

$$\perp \in \mathcal{U}.$$

To summarise, the following points are axiomatic to my formulation. These axioms cannot be stated within the formulation, because they describe its own properties, and not just those of the system it models.

Axiom 1 (Universality) *All possible concepts are represented in $\mathcal{U}$.*

Axiom 2 (Non-identity of concepts) *All concepts represented in $\mathcal{U}$ are mutually distinct.*

We need $\mathcal{U}$ because, if the conceptual space were *equal to* $\mathcal{U}$ (and $\mathcal{U}$ were therefore superfluous), any point in $\mathcal{U}$ could be reached by exploration. Therefore, transformation would be unnecessary. So, for transformational creativity to be meaningful, all conceptual spaces, $\mathcal{C}$, are required to be strict subsets of $\mathcal{U}$. Potentially, then, the type of conceptual spaces, $\mathtt{cs}$, is the power set of $\mathcal{U}$, $\mathcal{U}^*$, though it is unlikely that searching all of these spaces would yield results rated as highly creative.

Axiom 3 (Universal Inclusion 1) *All members of the type of conceptual spaces are strict subsets of $\mathcal{U}$. Therefore, tautologically,*

$$\forall \mathcal{C}:\mathtt{cs}.\mathcal{C} \subset \mathcal{U}$$

and, equivalently,

$$\mathtt{cs} = \mathcal{U}^*$$

We will also need to include $\perp$ in all conceptual spaces.

Axiom 4 (Universal Inclusion 2) *All conceptual spaces include $\perp$.*

$$\forall \mathcal{C}:\mathtt{cs}.\perp \in \mathcal{C}$$

So far, I have done nothing more precise than Boden's informal characterisation; I have merely pinned the ideas down to a specific formulation and pointed out a logical consequence (the necessity for the existence of $\mathcal{U}$ as distinct from $\mathcal{C}$). It is in the definition of $\mathcal{C}$, in terms of its own constraints, rather than its relation to $\mathcal{U}$, that we first find the necessity to clarify the existing ideas.

Defining the conceptual space

Boden (1990) does not explicitly acknowledge the existence of (an equivalent of) $\mathcal{U}$. Instead, she loosely defines her conceptual spaces in terms of a set of definitional rules, which we must therefore assume to be generative. However, she blurs the distinction between the rules which determine membership of the space (*i.e.,* which select members of $\mathcal{U}$ to be members of a particular $\mathcal{C}$, in my terms), and other rules which might allow the construction and/or detection of a concept represented by a point in the space. To remedy this, let us take two distinct rule sets, $\mathcal{R}$ and $\mathcal{T}$, being rules which constrain the space and rules which allow us to traverse it, respectively. In AI terms, then, $\mathcal{T}$ might be thought of as encoding a search strategy, perhaps including heuristics.

In order to introduce these sets of rules, we need a language in which to express them (assuming without loss of generality that both sets can be expressed in the same language). I will call this language $\mathcal{L}$, and suppose that it is the set of all sequences composed of some alphabet which may remain obscure for the moment. Therefore, by definition,

$$\mathcal{R} \subset \mathcal{L}, \ \ \mathcal{T} \subset \mathcal{L}.$$

Once given the language, and rule sets expressed in it, we need an interpretation function, $[\![.]\!]$, which generates from $\mathcal{L}$ a function to select members of sets. This will allow us to choose the members of $\mathcal{U}$ we want in $\mathcal{C}$:

$$\mathcal{C} = [\![\mathcal{R}]\!](\mathcal{U}).$$

This assumes that $\mathcal{R}$ contains only sequences which are meaningful under the interpretation $[\![.]\!]$.

Exploring the conceptual space

A similar approach is required for the application of the search strategy encoded in $\mathcal{T}$, though a little more computational mechanism is required. We need a means not just of *defining* the conceptual space, irrespective of order, but also of *enumerating* it, in a particular order, under the control of $\mathcal{T}$ – this is crucial to the simulation of a particular creative behaviour by a particular $\mathcal{T}$. By analogy, again, with the familiar approach to state space search, I introduce a function $\langle\!\langle . \rangle\!\rangle$, which, given a subset of $\mathcal{L}$, computes a function which maps a totally ordered subset of $\mathcal{C}$ to another totally ordered subset. As with $\mathcal{R}$ and $[\![.]\!]$, I assume that $\mathcal{T}$ does not contain sequences which have no interpretation under $\langle\!\langle . \rangle\!\rangle$. The ordering on the two subsets indicates the order in which the concepts in them are to be next considered for further development under $\mathcal{T}$, so the input, $\mathtt{c}_\mathtt{i}$, and output, $\mathtt{c}_\mathtt{o}$, of the function are successive states of an agenda.

$$\mathtt{c}_\mathtt{o} = \langle\!\langle \mathcal{R} \cup \mathcal{T} \rangle\!\rangle(\mathtt{c}_\mathtt{i}).$$

We need $\mathcal{R} \cup \mathcal{T}$ and not just $\mathcal{T}$ here because I have not ruled out the possibility that $\mathcal{T}$ generate members of $\mathcal{U}$ not in $\mathcal{C}$. We must be able to check for this.

It follows that we would begin some of our creative processes by computing

$$\langle\!\langle \mathcal{R} \cup \mathcal{T} \rangle\!\rangle(\{\perp\}).$$

We now have all the mechanism we need to model Boden's exploratory creativity as presented in 1990.

The value of two rule sets, $\mathcal{T}$ and $\mathcal{R}$

Importantly, separating the rules out into the sets $\mathcal{T}$ and $\mathcal{R}$ has given us the ability to consider alternative versions of $\mathcal{T}$ with any given $\mathcal{R}$, and, perhaps less obviously, *vice versa*. We can partition $\mathcal{C}$ into $\mathcal{C}_!$, concepts which have already been discovered, and $\mathcal{C}_?$, concepts which have not. Some versions of $\mathcal{T}$ may be effective in traversing $\mathcal{C}$ and in finding members of $\mathcal{C}_?$; some may be less so; and some may be good at finding members of $\mathcal{C}_?$ in some parts of $\mathcal{C}$ and not in others. Further, some elements in $\mathcal{C}$ may not even be accessible under $\mathcal{T}$. So now we have, for example, the ability to simulate two composers working in the different ways within the same style, for example, which was less clear in Boden's simpler formulation.

Evaluating members of the conceptual space

To do full justice to Boden's model as presented in 1998, we need one further set of rules, $\mathcal{E}$, such that $\mathcal{E} \subset \mathcal{L}$. This is the set of rules which allows us to evaluate any concept we find in $\mathcal{C}$ and determine its quality, according to whatever criteria we may consider appropriate – and, of course, it is not hard to imagine that $\mathcal{E}$ might be related to $\mathcal{T}$. However, I am making no attempt here to discuss or assess the value of any concepts discovered: while this issue is clearly fundamentally important (Boden 1998; Ritchie 2001; Pearce & Wiggins 2001), it can safely be left for another time. Suffice it to say here that the existing function $[\![.]\!]$ will be adequate to select those results of the creative process which are "valued" by $\mathcal{E}$, thus:

$$[\![\mathcal{E}]\!](\langle\!\langle \mathcal{R} \cup \mathcal{T} \rangle\!\rangle^{\diamond}(\{\perp\})),$$

where

$$\mathcal{F}^{\diamond}(X) = \bigcup_{n=0}^{\infty} \mathcal{F}^{n}(X),$$

$\mathcal{F}$ being a set-valued function of sets.

Characterising an exploratory creative system

To summarise, we now have the mechanism to describe an exploratory creative system in these terms with the following septuple:

$$\langle \mathcal{U}, \mathcal{L}, [\![.]\!], \langle\!\langle . \rangle\!\rangle, \mathcal{R}, \mathcal{T}, \mathcal{E} \rangle.$$

Exploring and transforming

Before proceeding to the formality of transformational creativity, there are some more issues to discuss in the exploratory context[1].

It follows from my characterisation of $\mathcal{T}$ as a search engine that there may be a fitness hypersurface associated with any combination of $\mathcal{C}$ and $\mathcal{T}$. The "landscape" so defined may be arbitrarily – perhaps extremely – convoluted. This means that it is possible to imagine finding c, a member of $\mathcal{C}_?$ which is, in general, very hard to find, but doing so *without changing* $\mathcal{T}$. Finding such a concept would presumably mark the creator as successful, especially if the other creators' $\mathcal{T}$s were less fortunate, for the discovery is unlikely. So here is a case where an exploratory creation might well be very significant – perhaps more signficant than many transformational creations.

Now, consider the converse situation. Suppose that a concept c is a member of $\mathcal{U}$, but not a member of $\mathcal{C}$, and that we *transform* $\mathcal{C}$ into $\mathcal{C}_1$, by transforming $\mathcal{R}$ into $\mathcal{R}_1$ – I discuss how this can happen below. Now we have exhibited transformational creativity, which, according to Boden, is more significant than exploratory creativity. But it may be the case that

$$\mathcal{C}_1 = \mathcal{C} \cup \{c\},$$

in which case it is hard to argue that the transformation is any more significant than the exploration in the account immediately above.

Now let us consider a third possibility, one which was not available to Boden because of her conflation of my $\mathcal{R}$ and $\mathcal{T}$: it is possible in principle for a concept which exists in $\mathcal{C}$ – and so is sanctioned by the constraints in $\mathcal{R}$ – to be unreachable by the rules specified in $\mathcal{T}$. This is an important point: it distinguishes what is *in principle* possible in a creative domain from what is *actually* possible according to the properties of a given creator. Therefore, another possibility for reaching the elusive discovery, c, above, is that

$$c \subset \mathcal{C}$$

but the rules of $\mathcal{T}$ make it inaccessible, or, stated formally,

$$c \notin \langle\!\langle \mathcal{R} \cup \mathcal{T} \rangle\!\rangle^{\diamond}(\{\perp\}).$$

So we have to introduce a different notion of transformational creativity – one which transforms not $\mathcal{R}$, the rules constraining the conceptual space, but $\mathcal{T}$. It is not hard to imagine that we can transform $\mathcal{T}$ into some $\mathcal{T}'$ such that c becomes accessible to our search.

From an external viewpoint, these different events are probably often indistinguishable, but the point is that they all fall short of Boden's informal definition of transformational creativity (that is, in the terms used here, changing $\mathcal{R}$) – which she argues is generally more significant than the exploratory kind.

So by making the argument more precise, we can demonstrate a potential weakness in Boden's characterisation: the boundary between exploratory and transformational creativity is ill-defined[2]. We are now in a position to argue that transformational creativity is unnecessary, and to conflate $\mathcal{U}$ and $\mathcal{C}$, thus producing a simpler characterisation.

However, I will argue that there is indeed a valid distinction between a kind of creativity that might be called "transformational" and a kind of creativity that might be called "exploratory". Before I can so so, however, we must consider transformational creativity in more detail.

Transformational creativity

Having gone some way towards formalising Boden's notion of exploratory creativity, we are now in a better position to

[1]All of this section begs a significant question of how $\mathcal{T}$ is acquired for any given creator. This paper cannot be long enough to cover that discussion, so it is merely mentioned, in the section headed "Guiding the creative process".

[2]This author is by no means the first to note this point.

say what transformational creativity actually is. It is at this point that we begin to see the benefits of this laborious formalisation. In this section, I discuss transformational creativity informally; I will treat it more formally in a later section.

Boden characterises her "transformational creativity" as the kind of creativity concerned not with finding members of $\mathcal{C}_?$ in a given conceptual space $\mathcal{C}$, but with transforming the rule set defining $\mathcal{C}$ so as to produce a new conceptual space, $\mathcal{C}_1$. In my terms, this might be achieved in two essential ways: by transforming $\mathcal{R}$ or by transforming $\mathcal{T}$(recall that, although changing $\mathcal{T}$ does not, by definition, change $\mathcal{C}$, any given $\mathcal{T}$ does not guarantee to reach all the elements of $\mathcal{C}$ – so a new $\mathcal{T}'$ may make a different subset of $\mathcal{C}$ *available*). Transforming $\mathcal{R}$ corresponds with changing the rules of the creative game being played – and, it seems, with what Boden calls "transformational" creativity. The second kind of transformation more naturally applies to the creative individual's *modus operandi* only – there seems to be no explicit analogue of this in Boden's formulation. Of course, it is possible for both kinds of transformation to happen at once.

Boden concludes, from what she portrays as historical precedent, that her transformational creativity (*i.e.* transforming $\mathcal{R}$) is somehow more significant, at least with respect to H-creativity, than exploratory creativity. This claim deserves some more scrutiny in the light of my division of the creative rules into $\mathcal{R}$ and $\mathcal{T}$.

First, let us consider the difference between $\mathcal{R}$ and $\mathcal{T}$.

Suppose, as Boden supposes, that $\mathcal{R}$ defines a set of concepts which is largely agreed among all creative agents interested in the area defined by $\mathcal{R}$. Then, almost by definition, any change in $\mathcal{R}$ has the force of a paradigm shift (albeit a little one), if it is valued highly enough by the *existing* evaluation rule set, $\mathcal{E}$, because it changes the *agreed* rules of the game. To ground this in an example: Kekulé's discovery of benzene rings, cited repeatedly by Boden (1990) as an example of transformational creativity, fits this bill. The idea was new because it allowed *loops* of carbon atoms, and not just chains. But the evaluation system was independent of the shape used: it was a meta-theoretic question of whether the theory explained the chemical data. Thus, Kekulé's new rule set was valued more highly under the *existing* evaluation rules than the pre-existing solutions.

On the other hand, $\mathcal{T}$, as I have proposed it, is not global or agreed: it is the "technique" of the individual creator. Therefore, a change in $\mathcal{T}$ is on a different scale from a change in $\mathcal{R}$: it may perhaps accelerate the agent's progress towards a good solution; it may even make accessible concepts which were not previously available to this particular agent – but it will not change the nature of space of possibilities, and thus will not constitute a paradigm shift. An archetype here would be the comparison between an expert organist, capable of convincingly harmonising a chorale, at first sight, in the style of J. S. Bach, and a beginning harmony student, struggling to do so for the first time. The rules of Bach Chorale harmony ($\mathcal{R}$) are common to both, but the techniques ($\mathcal{T}$) of the two are not.

For completeness, it is necessary to consider the case where a transformation in $\mathcal{R}$ is not necessarily adopted by all the creative agents working on $\mathcal{R}$. This case has, of course, been seen many times in history – I will give an archetypal example below. It can arise reasonably only where different creative agents working in a common $\mathcal{R}$ have different evaluation rule sets, $\mathcal{E}_i$ – the alternative case, where there are differing $\mathcal{R}_i$s, does not correctly describe the example situation. This raises an interesting question of how discovery of new ideas can lead to changes in the evaluation rule set itself. I will address this issue below.

Creativity and the meta-level

An aspect of this discussion which Boden (1990) leaves implicit is the formal relationship between exploratory and transformational creativity – one would need a formalisation of the kind presented here to do so. I now extend that formalisation to cover transformational creativity.

The idea at the root of Boden's transformational creativity is that of changing the rules which define her conceptual space. In my formulation, there are two such rule sets, $\mathcal{R}$ and $\mathcal{T}$. So, in my terms, transformational creativity consists in changing either $\mathcal{R}$ or $\mathcal{T}$ or both. The two sets are expressed in the language $\mathcal{L}$, which means that the result of the transformation(s) must also be in $\mathcal{L}$. We can usefully place a restriction on the results of these transformations: that they be well-formed in terms of whatever interpreter will interpret them. So we need a syntax checker, Σ, which will select the well-formed elements of $\mathcal{L}$.

We will also need to be able to construct elements of $\mathcal{L}$. Starting from the empty sequence, we can do this by application of a search algorithm, Ψ. Finally, we need to be able to evaluate the quality of the transformational creativity, with some function Ω. All of this is a standard AI approach. Consider now the relationship between the symbols introduced in this section and those in my characterisation of exploratory creativity, above.

We are searching the language $\mathcal{L}$. It contains all possible sequences derivable from its alphabet, some of which are relevant in the sense that they are interpretable by Ψ – Σ detects them. Suppose, then, that we give ourselves a new rule language, $\mathcal{L}_{\mathcal{L}}$, which allows us to construct sequences in $\mathcal{L}$, and a corresponding interpreter, $\widehat{[\![.]\!]}$. We can now specify Σ in terms of a rule set $\mathcal{R}_{\mathcal{L}}$, which picks those members of $\mathcal{L}$ which are syntactically well-formed with respect to Ψ. So, to pick the available well-formed sublanguage appropriate to Ψ, we evaluate

$$\widehat{[\![\mathcal{R}_{\mathcal{L}}]\!]}(\mathcal{L}).$$

By now, the reader will see where this argument is going. We can specify an interpreter, $\widehat{\langle\!\langle.\rangle\!\rangle}$, which will interpret a rule set $\mathcal{T}_{\mathcal{L}}$ applied to an agenda of potential sequences in $\mathcal{L}$. Finally, we can express our evaluation function, Ω, as a set of sequences, $\mathcal{E}_{\mathcal{L}}$, in $\mathcal{L}_{\mathcal{L}}$, and use $\widehat{[\![.]\!]}$, to evaluate it.

Our transformational creativity system can now be expressed in the septuple

$$\langle \mathcal{L}, \mathcal{L}_{\mathcal{L}}, \widehat{[\![.]\!]}, \widehat{\langle\!\langle.\rangle\!\rangle}, \mathcal{R}_{\mathcal{L}}, \mathcal{T}_{\mathcal{L}}, \mathcal{E}_{\mathcal{L}} \rangle,$$

which matches exactly the characterisation of exploratory creativity, suggesting that transformational creativity may (at least) be characterised as exploratory creativity at the (appropriate) meta-level.

In fact, we can go a stage further. If we allow ourselves a common, general specification language for our rule sets (in fact, another meta-language, but at a different kind of meta-level), we can simplify the system and use the same interpreters for both levels. So our transformational creativity system is now expressible as

$$\langle \mathcal{L}, \mathcal{L}_{\mathcal{L}}, [\![.]\!], \langle\!\langle . \rangle\!\rangle, \mathcal{R}_{\mathcal{L}}, \mathcal{T}_{\mathcal{L}}, \mathcal{E}_{\mathcal{L}} \rangle.$$

The only connection we have now not considered is that (if any) between $\mathcal{E}$ and $\mathcal{E}_{\mathcal{L}}$. I suggested above that, for a transformationally creative act to be valued, it would normally need to be valued under the criteria that governed the original search space. This begs the question of how to relate $\mathcal{E}$, which is defined over the exploratory/object-level universe $\mathcal{U}$, to the transformational/meta-level universe, $\mathcal{L}$.

Informally, and minimally, the transformation is valued if it admits a new concept which is valued to the available object-level conceptual space. We can express this, in terms of the exploratory creative system described above, by saying that $\mathcal{E}_{\mathcal{L}}$ is the rule set which selects pairs of $\mathcal{R}_{\mathcal{L}}$ and $\mathcal{T}_{\mathcal{L}}$ such that

$$[\![\mathcal{E}]\!](\{ \mathsf{c} \mid \mathsf{R} \in \langle\!\langle \mathcal{R}_{\mathcal{L}} \cup \mathcal{T}_{\mathcal{L}} \rangle\!\rangle^{\diamond}(\{\mathcal{R} \cup \mathcal{T}\}) \wedge \mathsf{c} \in \langle\!\langle \mathsf{R} \rangle\!\rangle^{\diamond}(\{\bot\})\})$$

is inhabited, where $^{\diamond}$ is as before. In other words, $\mathcal{E}_{\mathcal{L}}$ is the rule set which selects pairs of $\mathcal{R}_{\mathcal{L}}$ and $\mathcal{T}_{\mathcal{L}}$ such that new concepts are added to the conceptual space under consideration, and that those new concepts are valued by $\mathcal{E}$.

This meta/object level distinction raises some interesting questions. The most obvious is: if this relation holds between the object level of our creative domain and the meta-level of transformational creativity, what would it mean to take the same relation and apply it to the transformational level? However, I will leave these issues for future work.

To conclude the current section, let us return to the issue of the relative values of exploratory and transformational creativity, as introduced by Boden (1990). I have argued above that Boden's suggestion that transformational creativity is innately superior to exploratory creativity is not well founded in terms purely of the creative product. However, the meta-level notion of transformational creativity which I introduce above gives us another means of looking at the question, a means which Boden does not (at least, explicitly) use.

I suggest that, for true transformational creativity to take place, as described in my framework, above, the creator needs to be in some sense *aware* of the rules he/she/it is applying. This follows from the need to explore the space of possible rule sets defining the conceptual space. One might argue that serendipity – a happy accident – might account for creativity, and this can certainly be the case, but that would be a new category, of "serendipitous" creativity, and not transformational creativity, under my definition.

I make this point because it fits in very clearly with philosophical notions of art. Self-awareness is generally cited as the property which distinguishes the artist from the craftsperson[3]. That self-awareness, I suggest, is what makes a creator able to formalise his/her/its own $\mathcal{R}$ and $\mathcal{T}$ in terms of the meta-language $\mathcal{L}_{\mathcal{L}}$. So without that self-awareness, a creator *cannot* exhibit transformational creativity, though, conversely, of course, a creator *with* self-awareness may choose not to exercise it. I return to this point in my example, below.

Guiding the creative process

One area obviously missing from my discussion so far is the well-established work on metaphorical, analogical and case-based reasoning, such as that edited by Barnden (1999), which focusses on the discovery of new concepts in a conceptual space by means of transferring patterns of reasoning from one space to another, or between different parts of a single space. I have not addressed these aspects so far because they are orthogonal to my formalisation: their function is not to do with the definition of the space and the creative process – rather, they are *examples* of creative processes that can be described *within* those definitions. That is to say, the place for these methods in my formalisation is in the set $\mathcal{T}$ of creator's traversal rules – whether at the exploratory or transformational level.

However, this issue opens another another area of discussion, upon which I have previously only touched. While we now have an abstract characterisation of the conceptual space, the question of exactly how it is to be traversed has been conveniently hidden in $\mathcal{R}$, $\mathcal{T}$ and the interpreter, $\langle\!\langle . \rangle\!\rangle$. So the claim is that any means of traversing the conceptual space needs to be encoded using the language, $\mathcal{L}$. In many cases, this is a safe assumption, and needs no further discussion, but it is appropriate to consider at least one special case.

In my formalisation, both rule sets $\mathcal{R}$ and $\mathcal{T}$ are passed to $\langle\!\langle . \rangle\!\rangle$, on the grounds that $\mathcal{T}$ can generate concepts not acceptable according to $\mathcal{R}$. Such concepts, of course, may perhaps still valued by $\mathcal{E}$. The question is: what happens when this arises? Clearly, we might simply omit such concepts from the resulting space. But a much more interesting possibility is to allow such an event to trigger an introspection mechanism, and thus to consider the value of a directed transformation of the space to include the new concept. Techniques for machine learning can clearly be brought to bear here. Taking this approach on a repetitive basis, one can begin to imagine a sequence of creative steps, some of which reside within a given conceptual space, and some of which force the adaptation of the existing conceptual space into a new one. In the latter case, if the new space includes more concepts than just the one that forced its creation, this can lead to further discoveries, and so on. Thus, the conceptual space can develop in symbiosis with its traversal by the creative agent. These ideas clearly can lead to complex behaviours, and so will be discussed in isolation, elsewhere.

[3]Whether this is a valid distinction is an orthogonal issue, and is not discussed here.

Describing the development of art music

Introduction and Disclaimer

Now let us consider an example. An important caveat: I do not claim that this is in any sense *the correct* characterisation of the domain in question. It is merely a simplistic illustration, but one which I find quite useful. The example is the development of Western art music throughout the 2nd Millenium AD. Readers wishing to follow up the historical data here may refer to Abraham (1979). A useful dictionary of musical terms and concepts (and much more) may be found in Scholes (1970).

Definitions

First, we need some definitions:

- $\mathcal{U}$: All possible (partial) pieces of music
- $\mathcal{L}$: A language for defining musical constraint and construction rules
- $[\![.]\!]$: An interpreter for selecting musical pieces from $\mathcal{U}$ according to rule sets specified in $\mathcal{L}$
- $\langle\!\langle.\rangle\!\rangle$: A search engine for traversing $\mathcal{U}$ and its subsets according to rule sets specified in $\mathcal{L}$
- $\mathcal{R}_S$: The rules for composition of music in style S
- $\mathcal{T}_C$: The rules defining the technique of composer C
- $\mathcal{E}_p$: The rules defining the preference of person p

We can add, for convenience, the conceptual spaces $\mathcal{C}_S$, each of which contains all the possible (partial) pieces of music in style S, selected from $\mathcal{U}$ by $[\![\mathcal{R}_S]\!]$. In fact, it will not be necessary to use all of these definitions in this broad-brush example, but it is nevertheless useful to understand how the whole framework is constructed.

The Dark Ages and the Proto-Renaissance

Little is known about music in the Middle East and West in the period after the decline of Ancient Greek society and before around 800-850AD. Thereafter, the majority of what is known is church music, nearly all folk or popular music being passed by oral tradition and now, therefore, lost or changed.

We begin to see more formal, notated music in the 10th Century, again mostly from the church. Those limited manuscripts which are available contain almost exclusively monophonic or drone-based modal melodies, or occasionally melodies sung in mostly parallel intervals, known as *organum*[4]. This is the starting point of our creative simulation. We need a set of rules, $\mathcal{R}_{\mathtt{Modal}}$, which define that subset of all possible pieces of music which are in the *modal* style[5]. This gives us, in turn, $\mathcal{C}_{\mathtt{Modal}}$, which is (one way of expressing) the conceptual space of modal music.

The exact nature of the music – monophonic, drone-based, organum – and the different styles of different composers are appropriately modelled by different sets $\mathcal{T}_C$, traversing the same conceptual space in different ways. But those rules are so constructed as never to reach the music of later periods, involving, for example, true polyphony. So much of $\mathcal{C}_{\mathtt{Modal}}$ is uncharted at the beginning of this period, with most composers covering and covering again a small subset.

However, by the time of the so-called Proto-Renaissance (*c.*, 1125-), the beginnings of three- and four-part harmony are emerging. These developments all take place within the well-established framework of $C_{\mathtt{Modal}}$. Throughout this period, successive composers are exploring successive parts of the conceptual space with their individual $\mathcal{T}_C$s – the overall effect is one of a single creator exploring $C_{\mathtt{Modal}}$ with one grand, inclusive $\mathcal{T}$, though, of course, the actual process may be much more complex, with many steps and transformations, as suggested in the earlier section, "Guiding the creative process".

The music is, however, still very simple and restrained, with, for example, major thirds still being regarded as dissonant intervals requiring resolution: scores invariably end in unison or open fifths.

Ars Nova

During the fourteenth century, we see the establishment of true polyphony in music, notably with the French composer, Guillaume de Machaut.

From the point of view of our model, there is little to add here, other than "more of the same". The point is that we are amidst a sustained period of exploration of $\mathcal{C}_{\mathtt{Modal}}$.

The Renaissance period

By the 15th Century, more of the modal space has been explored, in different ways, leading to more chordally accompanied musics, or homophony, and in another direction, more development of polyphony.

Another strong trend during this time is towards a richer harmony – for example, cadences now often contain major or minor thirds, which were previously considered dissonant and therefore non-final.

All of this may be said to be achieved by exploratory creativity – the rules, $\mathcal{R}_{\mathtt{Modal}}$, governing the fundamental nature of harmony are not in fact changing, but the subsets of $R_{\mathtt{Modal}}$ explored by different composers are becoming larger.

A related question is raised, however, by the change in the perception of dissonance mentioned above. While it is clearly the case that the exploration of $\mathcal{C}_{\mathtt{Modal}}$ *admits* these new sounds, it is the evaluation function, $\mathcal{E}$, which *keeps* them. There is an interesting question to be considered of how "learning" interaction between the $\mathcal{E}_p$s and the $\mathcal{T}_C$s works, since there clearly has to be such an interaction for this kind of development to proceed. However, this question is left for further work.

The Baroque period

With the advent of the well tempered scale in the time of J. S. Bach, a curious change takes place. It might be described as a transformation in the prevailing $\mathcal{T}_C$s, but I

[4]Abraham refers to the homophonic *organa* of Hucbald, from the late 800s as polyphony, though this definition is debatable.

[5]Modal music, in fact, goes back at least as far as the Ancient Greeks, to the writings of Aristoxenus and Pythagoras, so having endured over 1000 years to this point in time, we can argue that it is a good basis for discussion.

would argue that it is in fact a transformation of $\mathcal{R}_{Modal}$ into something else. At first sight, the effect might be seen as a strong tendency to explore a *more* limited part of $\mathcal{C}_{Modal}$ than before: that part corresponding with diatonic or tonal music, $\mathcal{C}_{Tonal}$. However, in fact, the change in tuning system has made it possible to use *more* scales which are diatonic. Previously, under the just temperament system, the number of diatonic scales which could be played in tune was quite limited. The arrival of well-temperament meant that it was now possible to play in all keys without tuning problems. This meant in turn that it was possible to achieve musical effects in diatonic ways which were previously only available *via* different modes. Because of the categorical perception of pitch, which motivates the use of well-temperament in the first instance, we may say that the diatonic members of $\mathcal{C}_{Modal}$ are in $\mathcal{C}_{Tonal}$ – but $\mathcal{C}_{Tonal}$ contains many pieces which cannot be in $\mathcal{C}_{Modal}$.

Here, then, we are seeing our first signficant transformational creativity: the explicit, deliberate change of tuning system and the new space of possibilities it enables has made a few key individuals change the $\mathcal{R}$s of their personal conceptual spaces – the change then propagates quickly through musical society and becomes collective. It seems likely that this change was achieved by understanding what was potentially possible given the right tuning system and then finding the tuning system which would achieve it; in any case, the choice of the new system was explicity chosen for its improved range, as in J. S. Bach's *The Well-Tempered Keyboard*.

Comparing creativity – the Classical period

The classical period sees more refinement in the diatonic conceptual space, refining the notion and use of dissonance in music still further. A particularly noteworthy pair of musicians at this point are Joseph Haydn and Wolfgang Amadeus Mozart. It is widely assumed that Mozart was "the more creative" of the two, but, objectively, this is open to question. While history seems to suggest that Mozart produced "better" music, it was nevertheless Haydn who really defined the classical style which Mozart then improved. So $\mathcal{T}_{Haydn} \cap \mathcal{T}_{Mozart}$ is large compared with $\mathcal{T}_{Haydn} \cap \mathcal{T}_{C}$ where C is an earlier composer. It is easy to see that Haydn is in at least one sense more creative when the issues are thus expressed.

The Romantic period

Notwithstanding the restriction from modal to diatonic music, the tendency to explore more harmonically dense structures continues, and chromaticism begins to emerge. This music is still tonal, but it is stretching the boundaries of what can be called tonality, often to the consternation of successive generations of audience.

Nonetheless, the music is still essentially tonal, and so inhabits essentially the same conceptual space defined two thousand years earlier in Ancient Athens. What has changed is the amount of the conceptual space, $\mathcal{C}_{Tonal}$, covered by the search of a collective $\mathcal{T}$ representing the sum of musical exploration and accepted by a collective $\mathcal{E}$ becoming progressively more tolerant of dissonance.

Modernist music

The twentieth century saw the arrival of a new intellectualism in music, where experiment in method became as valued by some observers as much as or more than the creative output – so here we have an agreed change in $\mathcal{E}$, moving from a judgement on creative output to the same combined with a judgment on the nature of the creative process itself. This led to an explosion of styles, some retrospective, such as the modality of Vaughan Williams, and some quasi-retrospective, such as the neo-classicism of early Stravinsky, and some new, such as the experimentalism of Ives, Varèse and Cage. Here is another point, then, at which a change in $\mathcal{E}$ opens up a whole new area of conceptual space, and possibly of universe, for consideration. Indeed, many of the works in question would not even be considered as music under the definitions of earlier centuries.

Twelve-tone music

Arguably the most radical change, however, arose with Arnold Schoenberg's Opus 11 in 1920, the first piece deliberately not centred on a key note[6]. The tone-centred assumption of modality and tonality finally is shattered – and, importantly, it is shattered consciously and deliberately, along with associated notions, such as dissonance[7]. This, then, in both Boden's terms and mine, is another transformation. The followers of Schoenberg created music which inhabits a different space of possibilities from $\mathcal{C}_{Tonal}$ – we might call it $\mathcal{C}_{Twelve-note}$. By definition, *complete* members of $\mathcal{C}_{Twelve-note}$ cannot be members of $\mathcal{C}_{Tonal}$.

The difference between $\mathcal{C}_{Twelve-note}$ and $\mathcal{C}_{Tonal}$ is sufficiently great that no $\mathcal{T}$ designed for the latter will work for the former – so the Second Vienna School composers were forced to develop their own explicit methodology, based around Schoeberg's "twelve-note method". Society is still waiting for an $\mathcal{E}$ agreed enough to allow these composers to enter mainstream popularity.

Summary

In this section, I have illustrated how the development of music from around the 10th century to the time of writing may be outlined using my proposed formalism, and highlighted one or two places where doing so elucidates what was actually happening during that development. Clearly, however, there is much more work to be done in this area.

Conclusion and further work

I have presented a simple formalisation and a modest refinement of Boden's (1990) descriptive hierarchy of creativity. I have shown that Boden's transformational creativity is actually a kind of exploratory creativity, and I have illustrated the application of the formalism with a broad-brush example taken from music history.

[6]Schoenberg did not use the term *atonal* – rather, he preferred *twelve-note*, presumably because he understood the Western tendency to perceived and understand music tonally even when it is not intended to be so.

[7]"Dissonance is an outmoded concept." (Schoenberg 1974).

This paper is very much a beginning. There are many aspects of the work which remain unfinished, such as the question of what happens when we move to higher meta-levels in the exploratory/transformational heirarchy, and how interactions between different creative agents can cause individual learning and adaptation, and collective agreement in any of my rule sets.

In all, I conclude that Boden's characterisation, though essentially simple and perhaps even vague, actually captures rather more than one might first think. As such, it is a valuable philosophical tool, and should not be dismissed lightly.

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